UNIVERSITY OF TORONTO STUDIES

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No. 25: NOTE ON THE TEMPERATURE VARIATIONS IN THE SPECIFIC RESISTANCE OF HEUSLER'S ALLOYS,

BY H. A. McTAGGART AND J. K. ROBERTSON

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and
J. K. ROBERTSON, M.A.

Communicated by Professor J. C. McLENNAN.

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IV.—*Note on the Temperature Variations in the Specific Resistance of Heusler's Alloys.*

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(Communicated by Prof. J. C. McLennan, and read May 26 1908.)

INTRODUCTION.

The following note contains an account of a preliminary study of the specific resistance of several samples of the bronze alloys discovered a few years ago by Heusler.[1] There already exists as a result of the investigations of various experimenters, a considerable amount of information with regard to the nature and properties of these alloys, but no careful examination of their electrical resistance has up to the present been attempted.

A perusal of the literature bearing on the subject of Heusler's alloys shews a number of striking contrasts between their properties and that of many other alloys, as well as pure metals. They are magnetic, though composed of non-magnetic constituents; their permeability shews unusual variations accompanying the processes of cooling from high temperatures; their hysteresis effects depend on similar treatment; and they exhibit magnetostriction phenomena altogether different from those displayed by other well known magnetic substances. Consideration of these properties, and particularly of those which are subject to modifications by specific heat treatment, suggested the possibility of the existence of peculiarities in the values of the coefficient of resistance in some regions of temperature.

It became then a matter of interest and importance to examine the resistance of these alloys, not only at ordinary temperatures but also over as wide a range as possible, so as to observe as fully as may be the character of any variations which might occur in the specific resistance in consequence of temperature changes. To add, then, if possible, from this line of investigation, some further data which might help to explain the magnetic properties of these bronzes, the authors, at the suggestion of Prof. McLennan, carried out as time permitted, the series of observations described below.

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[1] Verh. d. Deut. Phys. Gesell, 5,219, 1903; Marburg Schriften, 237, 1904; Ann. d. Phys., 16,535, 1904; Electrician, June 16th, 1905; Phys. Rev., 96,335, 1905; Verh. d. Deut. Phys. Gesell, 7,133, 1905; Proc. Roy. Soc., 76,271, 1905; Phys. Rev., 23,498, 1906; Bulletin of Bureau of Standards, Washington, Vo 12, No. 2, p. 287, Aug., 1906; Verh. d. Deut. Phys. Gesell, March, 1907; Phy Rev., 24, 1907; Verh. d. Deut. Phys. Gesell., Jan., 1908.

Outline of Method:—The intention was to make determinations of the specific resistance at a considerable number of different temperatures, but lack of time confined the observations to five particular points—namely, that of liquid air, about —185° C., that of carbonic acid snow and ether, about 77° C., that of melting ice, boiling water, and that of paraffin heated to 160° C.

TABLE I.

No. of alloy.	Percentage Composition.			Atomic ratio of A to Mn.
	Al.	Mn.	Cu.	
1A.	8.0	32.1	59.8	.51
2, 2A.	9.7	25.6	64.6	.77
3, 3A, 3B.	14.3	28.6	57.1	1.01
4, 4A.	15.9	23.9	60.3	1.92

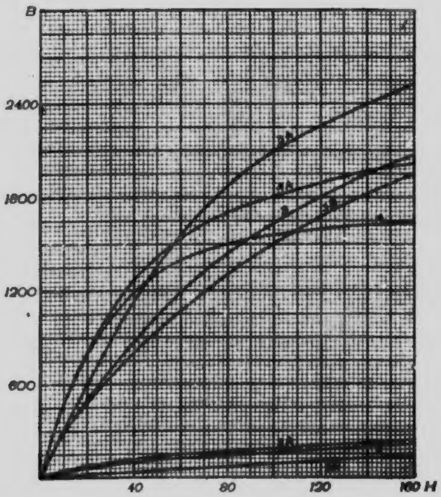

FIG. 1

Eight rods each about 15 cms. long, whose distinguishing marks are 1A, 2, 2A, 3, 3A, 3B, 4, 4A. and whose percentage composition is shewn in Table I were examined.

Before beginning the study of the resistance of the samples their permeability was roughly determined for purposes of comparison. To do this a ballistic method was employed, the rods being placed in a glass tube wound with a secondary coil, which was itself in turn placed inside a standard primary. No correction was made for end effects as a comparison of the relative magnetization values of the different specimens was all that was desired.

The curves given in Fig 1 shew graphically the values of B and H for each of the rods examined, and the numbers themselves from which the curves were plotted are given in Table II.

TABLE II.

Alloy 1A		Alloy 2		Alloy 2A		Alloy 3	
H	B	H	B	H	B	H	B
15.35	23.02	16.04	28.22	16.04	29.13	17.44	424.15
32.08	43.31	32.79	47.95	32.79	49.18	34.19	776.02
55.82	58.77	55.12	89.16	55.82	90.53	59.91	1179.20
75.36	73.59	75.36	118.59	76.06	120.64	77.45	1434.57
106.06	101.93	106.76	153.72	108.15	162.89	110.25	1733.56
130.48	116.03	131.88	175.86	131.88	195.16	136.07	1894.80
147.93	126.09	148.63	195.59	148.63	215.11	153.51	1993.15
163.28	131.41	163.28	203.54	166.07	217.87	168.86	2060.81
175.84	133.35	175.84	207.15	178.63	220.82	182.82	2110.22
187.01	138.02	188.40	210.77	193.29	212.24	193.98	2149.75

Alloy 3A		Alloy 3B		Alloy 4		Alloy 4A	
H	B	H	B	H	B	H	B
17.44	555.41	17.44	367.30	17.44	759.41	16.74	696.99
34.89	1021.38	34.19	664.41	32.49	1134.23	33.49	1101.79
58.61	1522.69	57.21	1045.36	56.52	1378.59	55.82	1472.04
78.85	1835.39	78.15	1308.23	77.45	1475.26	76.75	1662.45
111.64	2196.44	110.90	1633.01	117.23	1571.43	109.55	1853.23
136.07	2383.61	136.07	1811.83	134.67	1632.35	133.27	1947.48
153.51	2491.76	153.51	1930.08	153.51	1673.92	152.12	2005.48
168.86	2558.30	170.26	1999.48	167.47	1699.09	167.47	2043.43
181.42	2605.64	183.52	2052.35	180.73	1708.70	180.03	2072.34
193.29	2648.57	193.98	2087.73	190.49	1724.64	188.40	2093.58

To examine their resistance the rods were laid side by side about 1 cm. apart in two sets of four each, and their ends soldered together in series. In this way four rods at a time were placed in the bath and examined in succession. The resistance of each specimen was deduced from the observed value of the potential difference at the ends of a five cm. length of the alloy, and from the value of the current passing through it according to the equation—

$$R = \frac{V}{C};$$

and from this result the specific resistance was calculated according to the equation

$$\sigma = \frac{R\,A}{L}$$

where A = the cross section
L = the length of the specimen.

Apparatus:—The current traversing the alloys was supplied from a storage battery, a rheostat being used to make small adjustments when desired. To measure the current at any time, the difference of potential at the ends of a $\frac{1}{1000}$ ohm standard resistance in circuit with the alloys was observed by means of a Siemens and Halske potentiometer provided with a sensitive galvanometer.

To determine the potential difference at the ends of a 5 cm. length of the alloy, a pair of calipers fitted with ebonite arms bearing brass V-shaped tips with platinum edges made a sliding contact at any two points desired along the specimen and wires leading from the brass tips served to make connection with the same potentiometer, the readings for current and potential difference at the points of contact being taken in succession. To determine the resistance of the 5 cm. length of a specimen, the calipers were adjusted to a length of 10½ cms. and the difference of potential observed. The calipers were then shortened to 5½ cms. and the potential difference again noted. The difference of the two readings gave the potential difference at the ends of a 5 cm. length of a specimen, and from this, the dimensions of the rod being known, the specific resistance was deduced.

No special difficulty was encountered in preparing baths at the chosen temperatures. For the highest temperature a narrow copper vessel was used long enough to contain the alloys laid upon proper insulating blocks. The paraffin was heated by gas and kept at a constant temperature of 160° C.

For the lowest temperature a quantity of liquid air was poured over the alloys while resting in a narrow dish made of thin brass placed in a bed of wool. By this method the alloys soon reached a steady temperature, and as the liquid when covered by wool evaporated but slowly a constant temperature was easily maintained.

The next temperature, —77° C., was obtained by pouring a mixture of carbonic acid snow and ether into the same vessel as was used for the liquid air. the snow being obtained in the usual way by allowing the gas to expand under high pressure from the cylinder in which it was confined.

A mixture of ice and water gave the zero temperature, and a vessel of boiling water the temperature of 100° C.

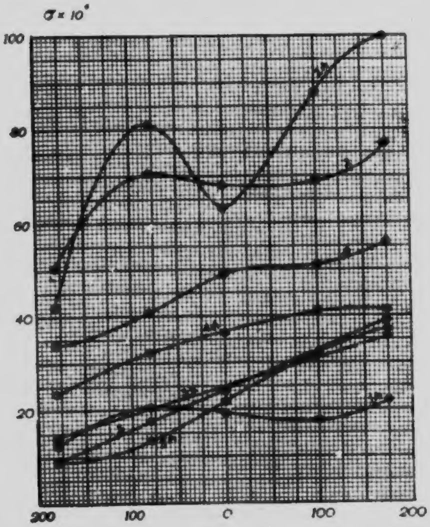

FIG. 2

To be certain before taking a reading that the baths had reached a steady state a nickel-iron thermocouple was used in connection with the potentiometer and the galvanometer mentioned above.

The results of the observations are given in Table III, and the points there given are joined by curves. as shewn in Fig. 2.

TABLE III.

Specific resistances of alloys.

Values of σ x 106 where σ is the specific resistance.

Temp.	1A	2	2A	3	3A	3B	4	4A
—180° C	12.87	50.30	41.90	9.29	9.48	14.02	33.09	23.8
— 77° C	20.80	70.26	81.00	17.79	13.66	20.44	40.50	32.0
0° C	19.31	68.36	63.70	24.48	22.09	24.35	49.39	36.8
100° C	18.78	68.89	88.10	31.88	32.18	31.63	51.51	41.4
160° C	22.58	77.80	100.50	39.65	37.72	36.57	56.61	41.8

Discussion.—From the values recorded in Table III it will be seen that the specific resistance of alloys No. 2 and No. 2A were exceptionally high, and although with the two alloys the resistances were determined for only a limited number of points it is evident from the form of the curves that the specific resistance of both underwent wide and irregular though somewhat similar variations. The existence of a maximum and a minimum value for the specific resistance of each in the range covered appears to be clearly established, and it is probable that had measurements for a larger number of temperatures been made these critical values would have been still further emphasized and more definitely determined.

Alloys Nos. 3. 3A and 3B, as well as Nos. 4 and 4A, shew very nearly a linear relation between specific resistances and temperatures, and in their behaviour approximate more closely to that of pure metals.

A comparison of the values of the specific resistance of these alloys with the known values of their constituents Cu. and Al. (that for Mn. apparently has not yet been determined) shews that all the specimens had a higher specific resistance than either of these two constituents. In this respect then the Heusler alloys resemble various alloys examined by Fleming and Dewar, and others. But, in the determinations of the latter the difference observed between the specific resistances of particular alloys and that of their respective components were not so large as that exhibited, for example by alloys 2, 2A.

This fact, coupled with the pronounced change in specific resistance which has been found to follow variations in the percentage composition of these alloys, make it desirable to have a more complete series of determinations for a larger number of specimens, and it is possible when these are made, that some additional information will be obtained which will assist in establishing a relation between the various phases of these alloys and the physical properties which they manifest.

It gives the writers pleasure to express, in this place, their sincere thanks to Prof. McLennan for his kindness in placing at their disposal the necessary apparatus to carry out the experimental work, and for his many helpful suggestions given from time to time during the investigation.

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The "Papers from the Physical Laboratories," issued as a special series of University of Toronto Studies, date from the year 1900. Nos. 1-17 were published by the Physical Department in a very limited edition and are no longer in print. For the sake of a complete record the numbering of the Papers, as forming a series of University of Toronto Studies, is made continous with the earlier series and commences with No. 18. The earlier numbers, except those given below, are not now available either for sale or gift.

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